Title: DEVICE AND METHOD FOR DETECTING A STATE OF A SENSOR IN THE EXHAUST SYSTEM OF A MOTOR VEHICLE

Abstract: The invention relates to a method for determining a state of at least one sensor (240; 270) of a motor vehicle (100; 112) which has an engine (230) and an exhaust system with a catalyst (260). The method comprises the steps of: - altering an NOx gas concentration downstream of the engine (230) by controlling operation of the engine (230) in a predetermined way; - determining a difference in a first NOx gas concentration upstream of said catalyst (260); - determining a difference in a second NOx gas concentration downstream of said catalyst; and - determining a state of said at least one sensor (240; 270) on the basis of said difference in the first NOx gas concentration and said difference in the second NOx gas concentration. The invention relates also to a computer programme product comprising programme code (P) for a computer (200; 210) for implementing a method according to the invention. The invention relates also to a device for determining a state of a sensor of a motor vehicle, and to a motor vehicle which is equipped with the device.

Fig. 2
Device and method for detecting a state of a sensor in the exhaust system of a motor vehicle

TECHNICAL FIELD

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The present invention relates to a method for detecting a state of a sensor of a motor vehicle. The invention relates also to a computer programme product comprising programme code for a computer to implement a method according to the invention. The invention relates also to a device for detecting a state of a sensor of a motor vehicle and to a motor vehicle which is equipped with the device.

BACKGROUND

15 There are now quite strict legal requirements in many countries as regards upper limit values for vehicle emissions. Vehicle manufacturers are constantly working on improvements to post-treatment systems to make it possible to further reduce undesirable exhaust gases, e.g. nitrous gases, also called nitrogen oxides (NO\textsubscript{x}), emitted by combustion engines in various types of vehicles, e.g. passenger cars, buses and trucks.

Regulation and adaptation of post-treatment systems which use SCR (selective catalytic reduction) technology are subject to various shortcomings. One such shortcoming is that the sensors used to measure emissions upstream and downstream of the SCR catalyst may be cross-sensitive for both NO\textsubscript{2} gas and ammonia (NH\textsubscript{3}). In cases where such a sensor is used downstream of the catalyst it is not possible to detect a relevant value for the NO\textsubscript{x} gas concentration in the exhaust gases, since the detector cannot distinguish between NO\textsubscript{x} gas and ammonia.

30 In a notional type of diagnosis of sensors for detecting NO\textsuperscript{*} in the emissions, it may therefore be necessary to shut off urea supply to the exhaust gases,
with consequent adverse environmental effects in that excessive amounts of nitrogen oxides are thereby released from the vehicle. Shutting off urea supply to the exhaust gases also has adverse fuel economy effects in that the period of no urea dosage is weighted into emission cycles of the vehicle's control system.

In another type of diagnosis of sensors for detecting NO\textsubscript{x} gas in the emissions, stored emission models may be used. However, this type of diagnosis entails excessive margins of error, since the estimated NO\textsubscript{x} gas concentrations are not reliable enough.

It is known that a certain storage of ammonia takes place in SCR catalysts during operation of the vehicle. More ammonia is thus stored in the catalyst during operation of the vehicle than is actually needed for reacting with the amount of NO\textsubscript{x} gas supplied. The amount of ammonia stored is temperature-dependent in that a smaller amount of ammonia can be stored in the catalyst at high temperatures and a larger amount of ammonia can be stored in the catalyst at low temperatures.

WO 2008/120649 describes a system capable of deciding whether a catalyst of a vehicle is or is not to be supplied with absorbed ammonia when fuel supply to an engine of the vehicle is limited while travelling at low speeds.

JP 2008/133780 describes a method for diagnosing a NO\textsubscript{x} sensor downstream of a catalyst of a vehicle. The diagnosis is performed during a state in which supply of reducing substances is halted to avoid affecting the catalyst.

There is a need to provide a method for diagnosing and determining any errors of one or more sensors for detecting NO\textsubscript{x} gas concentrations in emissions of a motor vehicle without urea supply being reduced to a minimum during this procedure.
SUMMARY OF THE INVENTION

An object of the present invention is to propose a novel and advantageous method for determining a state of a sensor in an exhaust system of a motor vehicle. A particular object of the present invention is to propose a novel and advantageous method for determining a state of a NO\textsubscript{x} sensor in an exhaust system of a motor vehicle.

Another object of the invention is to propose a novel and advantageous device and a novel and advantageous computer programme for determining a state of a sensor in an exhaust system of a motor vehicle. A particular object of the present invention is to propose a novel and advantageous device and a novel and advantageous computer programme for determining a state of a NO\textsubscript{x} sensor in an exhaust system of a motor vehicle.

A further object of the invention is to propose a method, a device and a computer programme for achieving a more robust determination of a state of a sensor of a motor vehicle.

A further object of the invention is to propose a method, a device and a computer programme for achieving a more accurate determination of a state of a sensor of a motor vehicle.

An object of the invention is to propose an alternative method for determining a state of a NO\textsubscript{x} sensor of a motor vehicle.

These objects are achieved with a method for determining a state of at least one sensor of a motor vehicle according to claim 1.
An aspect of the invention pertains to a method for determining a state of at least one sensor of a motor vehicle which has an engine and an exhaust system with a catalyst. The method comprises the steps of:
- altering a NO\textsubscript{x} gas concentration downstream of the engine by controlling operation of the engine in a predetermined way;
- determining a difference, in response to said altered NO\textsubscript{x} gas concentration, in a first NO\textsubscript{x} gas concentration upstream of said catalyst;
- determining a difference, in response to said altered NO\textsubscript{x} gas concentration, in a second NO\textsubscript{x} gas concentration downstream of said catalyst; and
- determining a state of said at least one sensor on the basis of said difference in the first NO\textsubscript{x} gas concentration and said difference in the second NO\textsubscript{x} gas concentration.

An aspect of the invention makes it possible to diagnose and adapt at least one NO\textsubscript{x} sensor by stepped raising of the NO\textsubscript{x} concentrations upstream and downstream of the catalyst. Stepped adjustments of the NO\textsubscript{x} concentrations in an exhaust system of the vehicle may be achieved by altering injection angles of at least one cylinder of the vehicle’s engine. By locking urea dosage to the SCR catalyst in all variables except mass flow it is possible for existing ammonia in the catalyst to be consumed by taking at least one NO\textsubscript{x} step. The urea dosage will not thereby be corrected. By thereafter effecting further NO\textsubscript{x} steps and comparing emission parameters determined at the first sensor situated upstream of the catalyst with emission parameters at a second sensor situated downstream of the catalyst it is possible to determine any gain error and offset error of the NO\textsubscript{x} sensor.

The method is easy to implement in existing motor vehicles. Software for determining a state of at least one sensor of a motor vehicle according to the invention may be installed in a control unit of the vehicle during the manufacture of the vehicle. A purchaser of the vehicle may thus have the possibility of selecting the function of the method as an option. Alternatively, software comprising programme code for effecting the innovative method for
determining a state of at least one sensor of a motor vehicle may be installed in a control unit of the vehicle on the occasion of upgrading at a service station, in which case the software may be loaded into a memory in the control unit. Implementing the innovative method is therefore cost-effective, particularly as no further sensors for detecting NO\textsubscript{x} gas concentrations in an exhaust system of the vehicle are required. Necessary hardware is currently already provided in the vehicle. The invention therefore represents a cost-effective solution to the problems indicated above. It is also likely that the vehicle will need fewer workshop visits, since automatic adaptation of misleading sensors can be effected according to the innovative method.

Software comprising programme code for determining a state of at least one sensor of a motor vehicle is easy to update or replace. Moreover, various portions of the software comprising programme code for determining a state of at least one sensor of a motor vehicle may be replaced independently of one another. This modular configuration is advantageous from a maintenance perspective.

The method may further comprise the step of:
- determining, before said control of the operation of the engine is initiated, whether a desirable flow state prevails in said exhaust system. If so, there is substantially no extra ammonia stored in the catalyst. It is thus with advantage made possible to apply the innovative method at relatively low temperatures in the catalyst, at which there may normally be a fairly large amount of ammonia storage during operation of the vehicle.

The method may further comprise the step of:
- setting, before said control of the operation of the engine is initiated, a value which represents a desired degree of stoichiometry.

The method may further comprise the steps of:
- determining a first parameter pertaining to said difference in the first \( \text{NO}_x \) gas concentration;
- determining a first parameter pertaining to said difference in the second \( \text{NO}_x \) gas concentration; and
- determining whether said at least one sensor has a gain error on the basis of the two first parameters.

The method may further comprise the steps of:
- determining a second parameter pertaining to said difference in the first \( \text{NO}_x \) gas concentration;
- determining a second parameter pertaining to said difference in the second \( \text{NO}_x \) gas concentration; and
- determining whether said at least one sensor has an offset error on the basis of the two second parameters.

The method may further comprise the step of:
- controlling urea injection in the exhaust system on the basis of the state determined of said at least one sensor.

The method may further comprise the step of:
- controlling operation of the engine in such a way as to cause a \( \text{NO}_x \) gas concentration downstream of the engine to increase in one or more substantially discrete steps.

The increase in said steps may be within a range of between 50 and 3000 ppm. The increase in said steps may be within a range of between 500 and 1000 ppm.

The operation of the engine may be controlled by acting upon an injection angle of at least one cylinder of the engine.
An aspect of the invention pertains to a device for determining a state of at least one sensor of a motor vehicle according to claim 10.

An aspect of the invention pertains to a device for determining a state of at least one sensor of a motor vehicle which has an engine and an exhaust system with a catalyst. The device comprises:
- means for altering a NO\textsubscript{x} gas concentration downstream of the engine by controlling operation of the engine in a predetermined way;
- means for determining a difference, in response to said altered NO\textsubscript{x} gas concentration, in a first NO\textsubscript{x} gas concentration upstream of said catalyst;
- means for determining a difference, in response to said altered NO\textsubscript{x} gas concentration, in a second NO\textsubscript{x} gas concentration downstream of said catalyst; and
- means for determining a state of said at least one sensor on the basis of said difference in the first NO\textsubscript{x} gas concentration and said difference in the second NO\textsubscript{x} gas concentration.

The device may further comprise means for determining, before said control of the operation of the engine is initiated, whether a desirable flow state prevails in said exhaust system.

The device may further comprise means for setting, before said control of the operation of the engine is initiated, a value which represents a desired degree of stoichiometry.

The device may further comprise means for determining a first parameter pertaining to said difference in the first NO\textsubscript{x} gas concentration;
- means for determining a first parameter pertaining to said difference in the second NO\textsubscript{x} gas concentration; and
- means for determining whether said at least one sensor has a gain error on the basis of the two first parameters.
The device may further comprise means for determining a second parameter pertaining to said difference in the first NOₓ gas concentration;
- determining a second parameter pertaining to said difference in the second NOₓ gas concentration; and
- determining whether said at least one sensor has an offset error on the basis of the two second parameters.

The device may further comprise means for controlling urea injection in the exhaust system on the basis of the state determined of said at least one sensor.

The method may further comprise means for controlling operation of the engine in such a way as to cause a NOₓ gas concentration downstream of the engine to increase in one or more substantially discrete steps.

The increase in said steps may be within a range of between 50 and 3000 ppm. The increase in said steps may be within a range of between 500 and 1000 ppm.

The above objects are also achieved with a motor vehicle which comprises the device for determining a state of at least one sensor of a motor vehicle. The vehicle may be a truck, bus or passenger car.

Alternatively, the invention may be applied to other vehicles or platforms which have a combustion engine. Examples of platforms other than land vehicles comprise watercraft, e.g. a boat or ship equipped with an engine which discharges emissions, or any freestanding generator, e.g. an electric generator run on diesel fuel.

An aspect of the invention pertains to a computer programme for determining a state of at least one sensor of a motor vehicle, which programme comprises programme code stored on a computer-readable medium for
causing an electronic control unit or another computer connected to the electronic control unit to perform steps according to any of claims 1-9.

An aspect of the invention pertains to a computer programme product comprising a programme code stored on a computer-readable medium for performing method steps according to any of claims 1-9 when said computer programme is run on an electronic control unit or another computer connected to the electronic control unit.

Further objects, advantages and novel features of the present invention will become apparent to one skilled in the art from the following details, and also by putting the invention into practice. Whereas the invention is described below, it should be noted that it is not confined to the specific details described. Specialists having access to the teachings herein will recognise further applications, modifications and incorporations in other fields, which are within the scope of the invention.
BRIEF DESCRIPTION OF THE DRAWINGS

For fuller understanding of the present invention and further objects and advantages thereof, the detailed description set out below should be read together with the accompanying drawings, in which the same reference notations denote similar items in the various diagrams, and in which:

Figure 1 illustrates schematically a vehicle according to an embodiment of the invention;

Figure 2 illustrates schematically a subsystem for the vehicle depicted in Figure 1, according to an embodiment of the invention;

Figure 3a is a schematic diagram showing NO\textsubscript{x} concentrations upstream of a catalyst of the vehicle as a function of time;

Figure 3b is a schematic diagram showing NO\textsubscript{x} concentrations upstream of a catalyst of the vehicle as a function of time;

Figure 4a is a schematic flowchart of a method according to an embodiment of the invention;

Figure 4b is a more detailed schematic flowchart of a method according to an embodiment of the invention; and

Figure 5 illustrates schematically a computer according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Figure 1 depicts a side view of a vehicle 100. The exemplified vehicle 100 comprises a tractor unit 110 and a trailer 112. The vehicle may be a heavy vehicle, e.g. a truck or a bus. The vehicle may alternatively be a passenger car.

The term "link" refers herein to a communication link which may be a physical connection such as an opto-electronic communication line, or a non-physical connection such as a wireless connection, e.g. a radio link or microwave link.
The terms "gain" and "gain error" in general refer herein respectively to a sensitivity and a proportional error in sensitivity of a sensor of the vehicle. In particular, the terms "gain" and "gain error" refer respectively to a sensitivity and a proportional error in sensitivity of a NO\textsubscript{x} sensor of the vehicle. The gain error of a NO\textsubscript{x} sensor may be determined by determining a characterising constant pertaining to a change in a NO\textsubscript{x} gas concentration upstream or downstream of a catalyst of the vehicle and by comparing this value with a reference value.

The terms "offset" and "offset error" in general refer respectively to a systematic displacement of a detected value and to an error pertaining to the systematic displacement of a detected error of a sensor of the vehicle. In particular, the terms "offset" and "offset error" refer respectively to a systematic displacement of a detected value and to an error pertaining to the systematic displacement of a detected value of a NO\textsubscript{x} sensor of the vehicle. The offset error of a NO\textsubscript{x} sensor may be determined by determining a characterising constant pertaining to a change in a NO\textsubscript{x} gas concentration upstream or downstream of a catalyst of the vehicle and by comparing this value with a reference value.

The term "stoichiometry" refers herein to a ratio between an existing NO\textsubscript{x} gas concentration and an existing concentration of ammonia (NH\textsubscript{3}). A ratio of 1 between NH\textsubscript{3} and NO\textsubscript{x} (NH\textsubscript{3}/NO\textsubscript{x}) represents a theoretically complete reduction of NO\textsubscript{x} when the amount of NH\textsubscript{3} is precisely as large as required. A degree of stoichiometry does not reduce all NO\textsubscript{x}. A degree of stoichiometry of 0.9 reduces 90% of NO\textsubscript{x} in an ideal catalyst and exhaust mass flow.

Figure 2 depicts schematically a subsystem 299 of the vehicle 100. The subsystem 299 is situated in the tractor unit 110. The subsystem 299 comprises an engine 230 intended to power the vehicle 100. The engine 230
is a combustion engine. The engine 230 may be a diesel engine with any desired number of cylinders, e.g. 4, 5 or 6 cylinders.

The exhaust gases generated by the engine during operation of the vehicle are arranged to be led in a first pipe 235 to a catalyst 260. The catalyst 260 in this embodiment example is a so-called SCR catalyst. The catalyst 260 is connected to a second pipe 265 which is arranged to lead the exhaust gases out from the vehicle 100 to its surroundings. One skilled in the art will appreciate that the subsystem 299 may comprise further components, e.g. particle filters. Such other components have been omitted to make the invention clearer.

A first sensor 240 is provided upstream of the catalyst 260 on the first pipe 235. The first sensor 240 is intended to measure a gas concentration of the exhaust gases in the first pipe 235. In particular, the first sensor 240 is intended to measure a NO$_x$ gas concentration in the exhaust gases in the first pipe 235. The first sensor 240 is intended to continuously detect a NO$_x$ gas concentration in the first pipe 235. The first sensor 240 is intended to detect in real time a NO$_x$ gas concentration in the first pipe 235. The first sensor 240 is arranged for communication with an emission control unit 220 via a link 241. The first sensor 240 is intended to continuously send to the emission control unit 220 signals containing information about a prevailing NO$_x$ gas concentration in the pipe 235. The emission control unit 220 is arranged to receive the signals sent from the first sensor 240.

In a similar way, a second sensor 270 is provided downstream of the catalyst 260 on the second pipe 265. The second sensor 270 is intended to measure a gas concentration of the exhaust gases in the second pipe 265. In particular, the second sensor 270 is intended to measure a NO$_x$ gas concentration in the exhaust gases in the second pipe 265. The second sensor 270 is intended to continuously detect a NO$_x$ gas concentration in the second pipe 265. The second sensor 270 is intended to detect in real time a
NO\textsubscript{x} gas concentration in the second pipe 265. The second sensor 270 is arranged for communication with the emission control unit 220 via a link 271. The second sensor 270 is intended to continuously send to the emission control unit 220 signals containing information about a prevailing NO\textsubscript{x} gas concentration in the second pipe 265. The emission control unit 220 is arranged to receive the signals sent from the second sensor 270.

The emission control unit 220 is arranged for communication with a fluid injector 250 via a link 251. The fluid injector 250 is situated on the first pipe 235. The emission control unit 220 is arranged to control the fluid injector 250 by means of control signals sent via the link 251. The fluid injector 250 is intended to inject a fluid into the first pipe 235 on the basis of the control signals received.

In this embodiment example, the fluid injector is adapted to injecting a liquid solution containing urea in the first pipe 235. An example of a liquid solution is AdBlue. A container (not depicted) is provided to contain the liquid solution. The container is flow-connected to the injector via a passage which is arranged to lead the liquid solution to the injector 250 for injection in the first pipe 235 as appropriate.

Injecting, for example, AdBlue or some other suitable liquid solution as above makes possible a catalytic process in the catalyst 260 whereby NO\textsubscript{x} gas reacts with ammonia (NH\textsubscript{3}), which may result in the formation of nitrogen gas (N\textsubscript{2}) and water (H\textsubscript{2}O).

One skilled in the art will appreciate that the first sensor 240, the second sensor 270 and the fluid injector 250 may be of suitable kinds and may accordingly be configured appropriately in the subsystem 299.

According to a version, an engine control unit 200 is arranged for communication with the emission control unit 220 via a link 221. The engine
control unit 200 is also referred to as a first control unit 200. The first control unit 200 is arranged to control the emission control unit 220 by continuously sending control signals to it. In the first control unit 200 an emission model may be stored in a memory. The first control unit 200 can by means of the stored emission model estimate a prevailing NO\textsubscript{x} gas concentration in the first pipe 235. The first control unit may also estimate by means of the stored emission model a prevailing NO\textsubscript{x} gas concentration in the second pipe 265. According to a version of the invention, the first control unit 200 is arranged to estimate a first NO\textsubscript{x} gas concentration level which should be present in the first pipe 235 in a given operating situation of the vehicle 100. This estimated first NO\textsubscript{x} gas concentration level in the first pipe 235 may serve as a reference level for an actually prevailing NO\textsubscript{x} gas concentration level in the first pipe 235. In a similar way, the first control unit 200 is arranged to estimate a second NO\textsubscript{x} gas concentration level which should be present in the second pipe 265 in a given operating situation of the vehicle 100. This estimated second NO\textsubscript{x} gas concentration level in the second pipe 265 may serve as a reference level for an actually prevailing NO\textsubscript{x} gas concentration level in the second pipe 265.

According to an example, the first control unit 200 may serve as master and the emission control unit may serve as slave.

The first control unit 200 is arranged to determine whether there is a substantially steady flow state of the catalyst 260. According to an example, the first control unit 200 is arranged to determine the substantially steady flow state on the basis of a prevailing temperature of the catalyst 260, or on the basis of how the prevailing temperature of the catalyst 260 varies with time. According to an example, the first control unit 200 is arranged to determine the substantially steady flow state on the basis of how the prevailing flow of the catalyst 260 varies with time. When it has determined that there is a substantially steady flow state, the first control unit 200 is arranged to choose a value which represents a desired degree of stoichiometry. The first control
unit 200 is arranged thereupon to lock urea dosage with respect to all variables other than gas mass flow in the exhaust system. The first control unit 200 is arranged to effect a NO\textsubscript{x} step in order to gradually empty the catalyst 260 of extra stored ammonia. The first control unit 200 is arranged to check whether there is extra stored ammonia in the catalyst 260. This may be done by a number of temporary raisings of the NO\textsubscript{x} concentrations in the first pipe 235.

It should be noted that the first control unit 200 is in general arranged to control urea injection to the first pipe 235 according to stored operating routines.

The urea dosage will not be corrected for changes in NO\textsubscript{x} gas during the innovative method. The first control unit 200 is arranged to alter a NO\textsubscript{x} gas concentration downstream of the engine 230 by controlling operation of the engine 230 in a predetermined way. Discrete NO\textsubscript{x} steps may be performed in this way. The first control unit 200 is further arranged to determine a difference in a first NO\textsubscript{x} gas concentration upstream of said catalyst 260 and to determine a difference in a second NO\textsubscript{x} gas concentration downstream of said catalyst. The first control unit 200 is arranged to determine a state of at least one of the NO\textsubscript{x} sensors 240 and 270 on the basis of said difference in the first NO\textsubscript{x} gas concentration and said difference in the second NO\textsubscript{x} gas concentration.

A second control unit 210 is arranged for communication with the first control unit 200 via a link 211. The second control unit 210 may be detachably connected to the first control unit 200. The second control unit 210 may be a control unit external to the vehicle 100. The second control unit 210 may be arranged to perform the innovative method steps according to the invention. The second control unit 210 may be used to cross-load software to the first control unit 200, particularly software for applying the innovative method. The second control unit 210 may alternatively be arranged for communication
with the first control unit 200 via an internal network in the vehicle. The second control unit 210 may be arranged to perform functions substantially similar to the first control unit 200, e.g. to determine a state of at least one of the first sensor 240 and the second sensor 270.

In the embodiment described with reference to Figure 2, the first sensor 240, the second sensor 270 and the injector 250 are signal-connected to the emission control unit 220. It should be noted that other configurations are feasible. For example, the first sensor 240, the second sensor 270 and the injector 250 might be signal-connected to the first control unit 200 and/or the second control unit 210. One skilled in the art will appreciate that sundry variants are feasible. Parts of the innovative method may by means of stored software be executed in the first control unit 200, the second control unit 210 and the emission control unit 220 or in a combination of them.

Figure 3a is a schematic diagram showing NO\textsubscript{x} gas concentrations C [ppm] upstream of the catalyst 260 of the vehicle 100 as a function of time T in seconds.

Before time T1\textsubscript{a} there is a certain concentration LO\textsubscript{a} of NO\textsubscript{x} gas in the first pipe 235. According to an example, this level LO\textsubscript{a} is 1000 ppm. Before raisings of the NO\textsubscript{x} gas concentration C upstream of the catalyst 260 are effected, a substantially steady flow state has to be reached at which an equilibrium state prevails in the catalyst 260. The substantially steady flow state may according to an example be determined on the basis of a prevailing temperature of the catalyst 260 or on the basis of how the prevailing temperature of the catalyst 260 varies with time.

After a substantially steady state has been determined, a value which represents a desired degree of stoichiometry is chosen. According to an alternative, a value is chosen which represents a desired degree of stoichiometry and which corresponds to a prevailing stoichiometry, i.e. a
current stoichiometry is frozen. According to another alternative, a predetermined value is chosen for the stoichiometry, e.g. 0.9 or 1.0. The chosen value representing a desired degree of stoichiometry is thereupon set in, for example, the first control unit 200, the second control unit 210 and/or the emission control unit 220 as a parameter in operating routines stored in them. This results in locking also of the urea dosage with respect to all variables other than gas mass flow in the exhaust system. This means according to an example that the amount of urea supplied to the first pipe 235 during a certain time is regulated on the basis of a prevailing gas mass flow in the first pipe 235.

At a first time T1a, after it has been determined that there is a substantially steady flow state in the vehicle's exhaust system, that a value representing a desired degree of stoichiometry has been chosen and that the urea dosage has been locked, the NO\textsubscript{x} gas concentration downstream of the engine 230 is altered in the first pipe 235 in a predetermined way. In this example the NO\textsubscript{x} gas concentration is increased to a first predetermined level L1a corresponding to 1200 ppm.

At a second time T2a, the NO\textsubscript{x} gas concentration downstream of the engine 230 is altered in the first pipe 235 in such a way that a temporary raising of the NO\textsubscript{x} gas concentration to a second predetermined level L2a is effected. Thereafter the NO\textsubscript{x} gas concentration is altered so that it again reaches the first predetermined level L1a. This procedure is repeated according to this example at three predetermined times. Thereafter a second phase begins, provided that an equilibrium state prevails in the catalyst. This equilibrium state represents a state in which no extra ammonia is stored in the catalyst 260. This equilibrium state may be determined on the basis of at least two consecutive responses of the NO\textsubscript{x} concentration downstream of the catalyst to said temporary raisings of NO\textsubscript{x} upstream of the catalyst 260, as described in more detail with reference to Figure 3b below.
At a predetermined time $T_{3a}$, the NO$_x$ gas concentration downstream of the engine 230 is altered in the first pipe 235 in such a way that any desired raising of the concentration is effected. In this case the level is raised from the first level $L_{1a}$ to the second level $L_{2a}$.

At a predetermined time $T_{4a}$, the NO$_x$ gas concentration downstream of the engine 230 is altered in the first pipe 235 in such a way that any desired raising of the concentration is effected. In this case the level is raised from the second level $L_{2a}$ to a third level $L_{3a}$. At a predetermined time $T_{5a}$, the NO$_x$ gas concentration downstream of the engine 230 is altered in the first pipe 235 back to the original level $L_{0a}$ or some other desired level.

According to this embodiment example, the first level $L_{1a}$ corresponds to 1200 ppm NO$_x$. According to this embodiment example, the second level $L_{2a}$ corresponds to 1300 ppm NO$_x$. According to this embodiment example, the third level $L_{3a}$ corresponds to 1400 ppm NO$_x$.

The predetermined steps performed during the first and second phases may correspond to a NO$_x$ gas concentration change $C$ within a range of between 50 and 3000 ppm.

Figure 3b is a schematic diagram showing NO$_x$ gas concentrations $C$ [ppm] downstream of the catalyst 260 of the vehicle 100 as a function of time $T$ in seconds.

Before a time $T_{1b}$, there is a certain NO$_x$ gas concentration $L_{0b}$ in the second pipe 265. According to an example, this level $L_{0b}$ is 100 ppm.

At the first time $T_{1b}$, the NO$_x$ gas concentration $C$ downstream of the catalyst is altered in the second pipe 265 on the basis of the engine control effected at time $T_{1a}$ as described above. In this example the NO$_x$ gas concentration is increased gradually to a first level $L_{ib}$ progressively as ammonia stored in
the catalyst 260 is consumed. The first level Li b corresponds in this example to 300 ppm. Times T1a and T1b are for natural reasons displaced chronologically so that time T1b is later than T1a. The same relative displacement prevails between times T2a and T2b, and so on, for the times indicated in Figures 3a and 3b.

At a second time T2b, the NOx gas concentration downstream of the catalyst 260 is altered in the second pipe 265 in such a way that a temporary raising of the NOx gas concentration is effected. In this example the response to the first concentration rise at time T2b downstream of the catalyst 260 is not complete, because there is still surplus ammonia stored in the catalyst.

However, the response to the two remaining concentration rises during the first phase is complete, and temporary raisings of NOx gas concentration levels downstream of the catalyst are effected. The two temporary increases in the NOx gas concentration are from a first level Li b to a level L2b.

After at least two temporary increases in the NOx gas concentration C which are of substantially equal magnitude downstream of the catalyst, provided that corresponding temporary increases in the NOx gas concentration C upstream of the catalyst are of substantially equal magnitude, it may be determined that an equilibrium state prevails in the catalyst.

It should be noted that said equilibrium state in the catalyst 260 may be determined in various ways. One of them is herein exemplified, viz. that indicated above.

At a time T3b, the NOx gas concentration downstream of the catalyst 260 is altered in the second pipe 265 on the basis of the change in the NOx gas concentration upstream of the catalyst 260 at time T3a. In this case the level is raised from the first level L1b to the second level L2b.
At a time T4b, the NO\textsubscript{x} gas concentration downstream of the catalyst 260 is altered in the second pipe 265 on the basis of the increase in the NO\textsubscript{x} gas concentration upstream of the catalyst 260 at time T4a. In this case the level is raised from the second level L2b to a third level L3b. At a time T5b, the NO\textsubscript{x} gas concentration downstream of the catalyst 260 is altered in the second pipe 265 back to the original level L0b, or some other desired level, on the basis of the lowering of the NO\textsubscript{x} gas concentration at time T5a.

In this embodiment example, the first level L1b corresponds to 300 ppm of NO\textsubscript{x} gas. In this embodiment example, the second L2b corresponds to 400 ppm of NO\textsubscript{x} gas. In this embodiment example, the third L3b corresponds to 500 ppm of NO\textsubscript{x} gas.

According to an aspect of the invention, a straight line equation y\textsubscript{1}=k\textsubscript{1}x+m\textsubscript{1} is determined for the stepped increases in the NO\textsubscript{x} gas concentrations upstream of the catalyst 260, and a corresponding straight line equation y\textsubscript{2}=k\textsubscript{2}x+m\textsubscript{2} for the stepped increases in the NO\textsubscript{x} gas concentrations downstream of the catalyst 260, as schematically depicted in Figure 3a and Figure 3b.

According to an aspect of the invention, the constants k\textsubscript{1} and k\textsubscript{2} may be compared with one another to determine on the basis thereof any gain error of the first sensor 240 and/or the second sensor 270. If the difference between the values of the constants k\textsubscript{1} and k\textsubscript{2} is greater than a predetermined limit value, it may be determined that there is a gain error. The absolute amount of the difference between the values of the constants k\textsubscript{1} and k\textsubscript{2} indicates the magnitude of the gain error between the first sensor 240 and the second sensor 270.

According to an aspect of the invention, the constants k\textsubscript{1} and k\textsubscript{2} may be compared with a constant k\textsubscript{3} arising from an emission model which estimates the NO\textsubscript{x} concentration upstream of the SCR catalyst in order to determine on
the basis thereof any gain error of the first sensor 240 and/or the second sensor 270.

According to an aspect of the invention, the constants, $m_1$ and $m_2$ may be compared with one another or with the predetermined reference value, such as a constant, e.g. zero (0), in order to determine on the basis thereof any offset error of the first sensor 240 and/or the second sensor 270. If the difference between the values of the constants $m_1$ and $m_2$ is greater than a predetermined limit value, it may be determined that there is an offset error. The absolute amount of the difference between the values of the constants $m_1$ and $m_2$ indicates the magnitude of the offset error between the first sensor 240 and the second sensor 270. Alternatively, an offset error may be determined by comparing the respective constants $m_1$ and $m_2$ with the predetermined value in order to determine the magnitude of the offset error.

Figure 4a is a schematic flowchart of a method for determining a state of at least one sensor of a motor vehicle which has an engine and an exhaust system with a catalyst, according to an embodiment of the invention. The method comprises a first step s401 comprising the steps of:

- altering a NO$_x$ gas concentration downstream of the engine by controlling operation of the engine in a predetermined way;
- determining a difference in a first NO$_x$ gas concentration upstream of said catalyst;
- determining a difference in a second NO$_x$ gas concentration upstream of said catalyst; and
- determining a state of said at least one sensor on the basis of said difference in the first NO$_x$ gas concentration and said difference in the second NO$_x$ gas concentration. The method ends after step s401.

Figure 4b is a schematic flowchart of a method for determining a state of a NO$_x$ sensor of a motor vehicle which has an engine and an exhaust system with an SCR catalyst, according to an embodiment of the invention.
The method comprises a first step s410 comprising the step of determining a flow state in the exhaust system of the vehicle 100. The flow state may be determined in a manner described in more detail with reference to the description of phase 1 in Figures 3a and 3b. Step s410 is followed by a step s420.

Method step s420 comprises the step of deciding whether the flow state determined is a substantially steady flow state. According to an example, the substantially steady flow state may be determined on the basis of a prevailing temperature of the catalyst 260 or on the basis of how the prevailing temperature of the catalyst 260 varies with time. If there is a substantially steady flow state, a subsequent step s430 is performed. If there is no substantially steady flow state, step s410 is performed again.

Method step s430 comprises the step of choosing a value which represents a desired degree of stoichiometry. According to one alternative, a value is chosen which represents a desired degree of stoichiometry and which corresponds to a prevailing stoichiometry, i.e. a current stoichiometry is frozen for the duration of the remaining method steps. According to another alternative, a predetermined value is chosen which represents a desired degree of stoichiometry, e.g. 0.9 or 1.0. The chosen value representing a desired degree of stoichiometry is thereupon set in, for example, the first control unit 200, the second control unit 210 and/or the emission control unit 220 as a parameter in operating routines stored in them. If a value other than that which represents a prevailing degree of stoichiometry is chosen, a new static flow state needs to be awaited before the procedure continues. In other words, in this case the \( \text{NO}_x \) gas concentration downstream of the catalyst 260 changes to a certain substantially constant level before the procedure continues.
Method step s430 comprises also the step of locking urea dosage with reference to all variables except gas mass flow in the exhaust system. According to an example, this means that the amount of urea supplied to the first pipe 235 during a certain time is regulated on the basis of a prevailing gas mass flow in the first pipe 235. Step s430 is followed by a step s435.

Method step s435 comprises the step of acting upon the catalyst 260. It comprises the step of effecting a stepped increase in NO\textsubscript{x} gas concentrations in the first pipe 235 from a level LO\textsubscript{a} to a level L1\textsubscript{a}, as illustrated in Figure 3a. The catalyst is thereby acted upon in such a way that extra ammonia stored in it is gradually consumed.

Step s435 comprises also the step of determining whether there actually is a desirable flow state in said exhaust system. The desirable flow state is a state in which substantially no extra amount of ammonia is stored in the catalyst 260. The desirable flow state may be a state in which an equilibrium state with regard to NO\textsubscript{x} and ammonia prevails. According to an example, this desirable flow state is determined by effecting any desired number of temporary rises of the NO\textsubscript{x} gas concentration in the first pipe 235. With a certain delay, corresponding temporary raisings of the NO\textsubscript{x} gas concentration in the second pipe 265 may be detected. If two consecutive raisings of the NO\textsubscript{x} gas concentration in the second pipe 265 are of substantially equal magnitude, it may be determined that a desirable flow state prevails in said exhaust system. This brings to an end phase 1, which is described in more detail with reference to Figure 3a and Figure 3b. Step s435 is followed by a step s440.

Method step s440 comprises the step of taking remedial action. More specifically, remedial action is taken in order, in at least one discrete step, to raise the NO\textsubscript{x} gas concentration upstream of the catalyst 260. This may for example be done by controlling the injection angle $\alpha$ for at least one cylinder of the engine 230 of the vehicle 100. With a certain delay, a corresponding
increase in the NO\textsubscript{X} gas concentration downstream of the catalyst 260 will take place. Step s440 is followed by a step s450.

Method step s450 comprises the step of determining emission parameters pertaining to the NO\textsubscript{X} gas concentration increases upstream and downstream of the catalyst. This is described in more detail with reference to, for example, Figures 3a and 3b. The emission parameters are the constants $k_1$, $k_2$, $m_1$ and $m_2$ determined. Step s450 comprises also the step of determining any gain error of at least one of the NO\textsubscript{X} sensors 240 and 270. Any gain error of the at least one NO\textsubscript{X} sensor 240 and 270 may be determined on the basis of the constants $k_1$ and $k_2$ determined. Any offset error may be determined on the basis of the parameters $m_1$ and/or $m_2$ determined. In a mutual comparison of the constants $k_1$ and $k_2$, either the first sensor 240 or the second sensor 270 may serve as reference. In a mutual comparison of the constants $m_1$ and $m_2$, either the first sensor 240 or the second sensor 270 may serve as reference. Step s450 is followed by a step s460.

Method step s460 comprises the step of, where appropriate, adapting urea dosage to cater for any gain error determined and/or any offset error determined. The adaptation is intended to correct automated direct or indirect urea dosage of the subsystem 299. The method ends after step s460. Thereupon the stoichiometry is regulated according to stored operating routines and the subsystem 299 resumes normal operation of the SCR catalyst.

Figure 5 is a diagram of a version of a device 500. The control units 200, 210 and 220 described with reference to Figure 2 may in a version comprise the device 500. The device 500 comprises a non-volatile memory 520, a data processing unit 510 and a read/write memory 550. The non-volatile memory 520 has a first memory element 530 in which a computer programme, e.g. an operating system, is stored for controlling the function of the device 500. The device 500 further comprises a bus controller, a serial
communication port, I/O means, an AID converter, a time and date input and transfer unit, an event counter and an interruption controller (not depicted). The non-volatile memory 520 has also a second memory element 540.

A computer programme P is provided which comprises routines for determining a state of at least one sensor of a motor vehicle according to the innovative method. The programme P comprises routines for determining emission parameters pertaining to the respective NOx gas concentrations upstream and downstream of catalyst. The programme P comprises routines for, where appropriate, using the emission parameters determined as a basis for adapting any gain error determined and/or offset error determined, in accordance with the innovative method. The programme P may be stored in an executable form or in compressed form in a memory 560 and/or in a read/write memory 550.

Where it is stated that the data processing unit 510 performs a certain function, it means that the data processing unit 510 effects a certain part of the programme which is stored in the memory 560 or a certain part of the programme which is stored in the read/write memory 550.

The data processing device 510 can communicate with a data port 599 via a data bus 515. The non-volatile memory 520 is intended for communication with the data processing unit 510 via a data bus 512. The separate memory 560 is intended to communicate with the data processing unit 510 via a data bus 511. The read/write memory 550 is intended to communicate with the data processing unit 510 via a data bus 514. The links 211, 221, 251 and 271, for example, may be connected to the data port 599 (see Figure 2).

When data are received on the data port 599, they are stored temporarily in the second memory element 540. When input data received have been temporarily stored, the data processing unit 510 will be ready to effect code execution in a manner described above. According to a version, signals
received on the data port 599 contain information about a prevailing NO\textsubscript{x} gas concentration in the first pipe 235. According to a version, signals received on the data port 599 contain information about a prevailing NO\textsubscript{x} gas concentration in the second pipe 265. The signals received on the data port 599 may be used by the device 500 to determine a state of at least one of the first sensor 240 and the second sensor 270. This state comprises a state pertaining to any gain error determined and/or any offset error determined of at least one NO\textsubscript{x} sensor of the vehicle 100.

Parts of the methods herein described may be applied by the device 500 by means of the data processing unit 510 which runs the programme stored in the memory 560 or the read/write memory 550. When the device 500 runs the programme, methods herein described are executed.

The foregoing description of the preferred embodiments of the present invention is provided for illustrative and descriptive purposes. It is not intended to be exhaustive, nor to limit the invention to the variants described. Many modifications and variants will obviously suggest themselves to one skilled in the art. The embodiments have been chosen and described in order best to explain the principles of the invention and the practical applications thereof and hence to make it possible for specialists to understand the invention for various embodiments and with the various modifications appropriate to the intended use.
CLAIMS

1. A method for determining a state of at least one sensor (240; 270) of a motor vehicle (100; 112) which has an engine (230) and an exhaust system with a catalyst (260), said at least one sensor being situated in said exhaust system downstream and/or upstream of said catalyst, characterised by the steps of:
   - altering a NOₓ gas concentration downstream of the engine (230) by controlling operation of the engine (230) in a predetermined way;
   - determining a difference, in response to said altered NOₓ gas concentration, in a first NOₓ gas concentration upstream of said catalyst (260);
   - determining a difference, in response to said altered NOₓ gas concentration, in a second NOₓ gas concentration upstream of said catalyst (260); and
   - determining a state of said at least one sensor (240; 270) on the basis of said difference in the first NOₓ gas concentration and said difference in the second NOₓ gas concentration.

2. A method according to claim 1, further comprising the step of:
   - determining (s435), before said control of the operation of the engine is initiated, whether a desirable flow state prevails in said exhaust system.

3. A method according to claim 1 or 2, further comprising the step of:
   - setting (s430), before said control of the operation of the engine (230) is initiated, a value which represents a desired degree of stoichiometry.

4. A method according to any one of the foregoing claims, further comprising the steps of:
   - determining a first parameter (k₁) pertaining to said difference in the first NOₓ gas concentration;
   - determining a first parameter (k₂) pertaining to said difference in the second NOₓ gas concentration; and
- determining whether said at least one sensor (240; 270) has a gain error on the basis of the two first parameters \((k_1, k_2)\).

5. A method according to any one of the foregoing claims, further comprising the steps of:
- determining a second parameter \((m_1)\) pertaining to said difference in the first \(\text{NO}_x\) gas concentration;
- determining a second parameter \((m_2)\) pertaining to said difference in the second \(\text{NO}_x\) gas concentration; and
- determining whether said at least one sensor (240; 270) has an offset error on the basis of the two second parameters \((m_1, m_2)\).

6. A method according to any one of the foregoing claims, further comprising the step of:
- controlling operation of the engine (230) in a way which causes a \(\text{NO}_x\) gas concentration downstream of the engine (230) to increase in one or more substantially discrete steps.

7. A method according to claim 6, in which the increase in said steps is within a range of between 50 and 3000 ppm.

8. A method according to any one of the foregoing claims, in which the operation of the engine (230) is controlled by acting upon an injection angle \((\alpha)\) of at least one cylinder of the engine (230).

9. A device for determining a state of at least one sensor (240; 270) of a motor vehicle (100; 112) which has an engine (230) and an exhaust system with a catalyst (260), said at least one sensor being situated in said exhaust system downstream and/or upstream of said catalyst, characterised by:
- means (200) for altering a \(\text{NO}_x\) gas concentration downstream of the engine (230) by controlling operation of the engine (230) in a predetermined way;
- means (240; 220; 200; 210) for determining a difference, in response to said altered NO\textsubscript{x} gas concentration, in a first NO\textsubscript{x} gas concentration upstream of said catalyst (260);  
- means (270; 220; 200; 210) for determining a difference, in response to said altered NO\textsubscript{x} gas concentration, in a second NO\textsubscript{x} gas concentration downstream of said catalyst (260); and 
- means (220; 200; 210) for determining a state of said at least one sensor (240; 270) on the basis of said difference in the first NO\textsubscript{x} gas concentration and said difference in the second NO\textsubscript{x} gas concentration.

10. A device according to claim 9, further comprising:
- means (220; 200; 210) for determining, before said control of the operation of the engine (230) is initiated, whether a desirable flow state prevails in said exhaust system.

11. A device according to claim 9 or 10, further comprising:
- means (200; 210) for setting, before said control of the operation of the engine (230) is initiated, a value which represents a desired degree of stoichiometry.

12. A device according to any one of claims 9-11, further comprising:
- means (200; 210) for determining a first parameter (k\textsubscript{1}) pertaining to said difference in the first NO\textsubscript{x} gas concentration; 
- means (200; 210) for determining a first parameter (k\textsubscript{2}) pertaining to said difference in the second NO\textsubscript{x} gas concentration; and  
- (means 200; 210) for determining whether said at least one sensor (240; 270) has a gain error on the basis of the two first parameters (k\textsubscript{1}, k\textsubscript{2}).

13. A device according to any one of claims 9-12, further comprising:
- means (200; 210) for determining a second parameter (m-i) pertaining to said difference in the first NO\textsubscript{x} gas concentration;
- means (200; 210) for determining a second parameter ($m_2$) pertaining to said difference in the second NO$_x$ gas concentration; and
- means (200; 210) for determining whether said at least one sensor (240; 270) has an offset error on the basis of the two second parameters ($m_1, m_2$).

14. A device according to any one of claims 9-13, further comprising:
- means (200; 210; 220) for controlling urea injection in the exhaust system on the basis of the state determined of said at least one sensor (240; 270).

15. A device according to any one of claims 9-14, further comprising:
- means (200; 210) for controlling operation of the engine (230) in a way which causes a NO$_x$ gas concentration downstream of the engine (230) to increase in one or more substantially discrete steps.

16. A device according to claim 15, in which the increase in said steps is within a range of between 50 and 3000 ppm.

17. A device according to any one of claims 9-16, whereby the operation of the engine (230) is controlled by acting upon an injection angle ($\alpha$) of at least one cylinder of the engine (230).

18. A motor vehicle (100; 110) comprising a device according to any one of claims 9-17.

19. A motor vehicle (100; 110) according to claim 18, which vehicle is any from among truck, bus or passenger car.

20. A computer programme (P) for determining a state of a sensor of a motor vehicle, which computer programme (P) comprises programme code for causing an electronic control unit (200; 500) or another computer (210; 500) connected to the electronic control unit (200; 500) to perform steps according to any one of claims 1-8.
21. A computer programme product comprising a programme code stored on a computer-readable medium for performing method steps according to any one of claims 1-8 when said computer programme is run on an electronic control unit (200; 500) or another computer (210; 500) connected to the electronic control unit (200; 500).
Start

Determine

Ends

Fig. 4a

Start

Determine flow resistance

No

Is static flow state fulfilled?

Yes

Choose stoichiometry; Lock urea dosage

Acts upon catalyst

Take remedial action

Determine

Adjusts

Ends

Fig. 4b
**INTERNATIONAL SEARCH REPORT**

**International application No.**
PCT/SE2011/050360

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**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC: F01 N, F02D

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

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

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**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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Further documents are listed in the continuation of Box C.

See patent family annex.

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Name and mailing address of the ISA/SE
Patent- och registreringverket
Box 5055
S-102 42 STOCKHOLM
Facsimile No. +46 8 666 02 86

Authorized officer
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**INTERNATIONAL SEARCH REPORT**

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International Patent Classification (IPC)

F01N 77/00 (2006.01)  
F02D 41/14 (2006.01)

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