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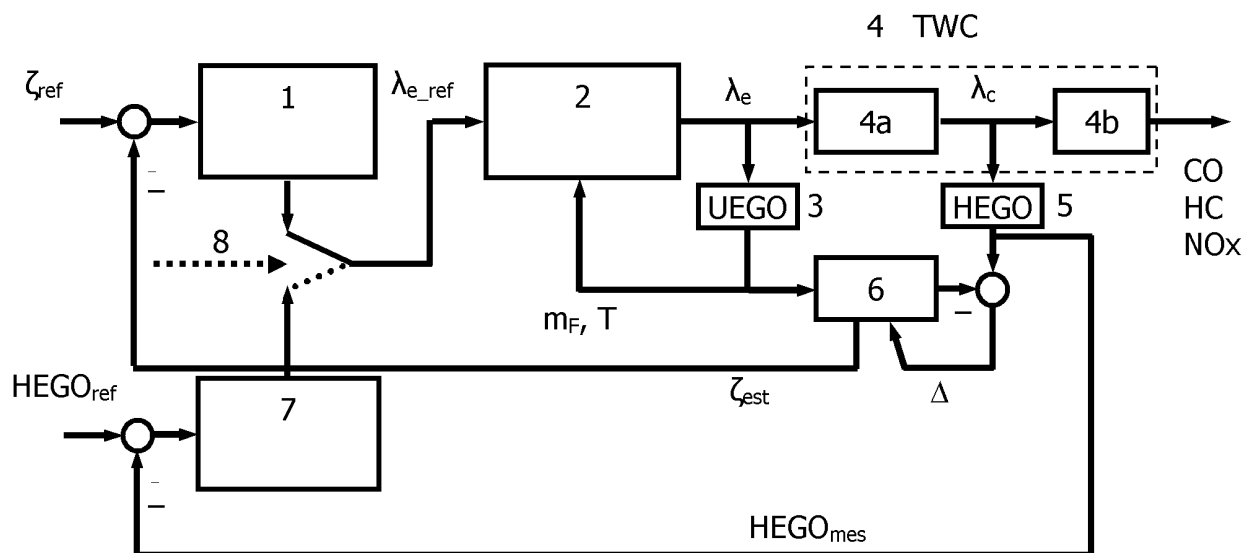
AL BA HR LV MK YU(71) Applicant: **Ford Global Technologies, LLC, A****subsidiary of Ford****Motor Company****Dearborn, MI 48126 (US)**

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• **Edwards, Jerome****CV32 7HS, Leamington Spa (GB)**• **Balenovic, Mario****5645 KT, Eindhoven (NL)**(74) Representative: **Drömer, Hans-Carsten et al****Ford-Werke Aktiengesellschaft,****Patentabteilung NH/DRP,****Henry-Ford-Strasse 1****50725 Köln (DE)****(54) Method and system for the control of an internal combustion engine with a three-way catalyst**

(57) The invention relates to a control system and a control method for an internal combustion engine (2) with a three-way catalyst TWC (4). A lambda-controller (7) of the system controls in a closed loop the lambda-value (λ_c) of the exhaust gas within or behind the TWC (4). Besides this, an oxygen-storage-controller (1) controls the internal combustion engine (2) such that the level of

oxygen stored in the TWC (4) remains within predetermined limits, thus guaranteeing that the TWC (4) has enough capacity to deal with transient rich or lean deviations in the composition of the exhaust gas. The oxygen-storage-controller (1) preferably relies on a catalyst-model (6) that estimates the level (ζ_{est}) of oxygen stored in the TWC.

**Fig. 1**

Description

[0001] The invention relates to a method and a control system for an internal combustion engine with a three-way catalyst.

[0002] In order to comply with present and future emission legislation for automotive vehicles, it is extremely important to operate exhaust gas aftertreatment devices with optimal efficiency. Thus it is well known for three-way catalysts (TWC; they remove simultaneously emissions of hydrocarbons HC, nitrogen-oxides NO_x and carbon monoxide CO from the exhaust gas) to control the air-fuel-ratio or lambda-value behind the catalyst in a feedback loop. Due to delays in said control loop it is however possible that the catalyst is not working optimally during transient conditions in the exhaust gas.

[0003] Based on this situation it was an object of the present invention to provide means for an improved and inexpensive control of an internal combustion engine with a three-way catalyst that are particularly able to deal with transient conditions.

[0004] This object is achieved by a control system according to claim 1 and a method according to claim 8. Preferred embodiments are disclosed in the dependent claims.

[0005] According to its first aspect the invention relates to a control system for an internal combustion engine with a three-way catalyst (TWC). Said control system may be implemented by means known in the art, for example by a microprocessor with associated software or by dedicated electronic circuits. The control system comprises the following components in a parallel (i.e. not cascaded) arrangement:

a) An oxygen-storage-controller that is adapted to control the internal combustion engine such that the level of oxygen stored in the TWC lies within predetermined oxygen-storage-limits. The level of stored oxygen may particularly be expressed as a fraction or a percentage of the maximal amount of oxygen that can be stored in the TWC. Typically the oxygen storage level in the TWC is desired to lie between 10% to 60%, preferably 20% to 50%.

b) A lambda-controller that is adapted to control the internal combustion engine such that the lambda value of the exhaust gas within or behind the TWC lies within predetermined lambda-limits. As usual, the lambda value (λ) is defined as the amount of air present in a gas relative to the amount of air that is needed for the combustion of the fuel present in the gas. Thus values $\lambda > 1$ correspond to a lean, values $\lambda < 1$ to a rich, and the value $\lambda = 1$ to a stoichiometric air-fuel mixture. It is known in the state of the art that the lambda-limits for an optimal efficiency of a TWC are close to the stoichiometric value, for example with $\lambda_{low} = 0.98$ and $\lambda_{high} = 1.02$.

Both the oxygen-storage-controller and the lambda-

controller may for example steer the internal combustion engine by determining the (desired) air-fuel-ratio of the combustion in the engine.

[0006] The control system described above takes the level of oxygen stored in the TWC into account and guarantees that it lies within predetermined optimal limits. These limits can be determined such that the TWC behaves robust with respect to transient deviations of the exhaust gas composition from the optimal value, i.e. such that the TWC does not become severely ineffective if the exhaust gas is momentarily too rich or too lean.

[0007] As the oxygen-storage-controller and the lambda-controller pursue separate objectives, their control activities must be coordinated. While this might for example be achieved by a weighted combination of their outputs, it is preferred to give the oxygen-storage-controller priority. Thus the lambda-controller is only operative if the level of oxygen in the TWC lies within the predetermined oxygen-storage-limits such that the oxygen-storage-controller is idle.

[0008] The lambda-controller preferably operates in a closed loop comparing the measured lambda value with or behind the TWC with a desired lambda value. For the measurement of the lambda value, the control system optionally comprises at least one heated exhaust gas oxygen (HEGO) sensor as it is well known in the state of the art.

[0009] In a preferred embodiment of the invention, the oxygen-storage-controller is linked to a catalyst-model that is used to predict the level of oxygen stored in the TWC. Thus there is no need for additional sensors or other expensive equipment in order to measure the oxygen content directly.

[0010] The aforementioned catalyst-model preferably receives as input signals the lambda value, the mass flow and/or the temperature of the exhaust gas in front of and/or behind the TWC. Based on these variables, the catalyst-model can estimate the level of oxygen stored in the TWC with good precision.

[0011] In order to improve the reliability of the catalyst-model, it may comprise an adaptation unit that is able to adjust the catalyst-model based on a comparison between the modeled and the measured lambda value with or behind the TWC. Said lambda value can be readily derived from the catalyst-model additionally to the required prediction of the level of stored oxygen. The measured lambda value is normally already available, too, as the feedback signal for the lambda-controller.

[0012] The control system may furthermore comprise a memory (e.g. ROM, RAM, hard disc etc.) in which the predetermined oxygen-storage-limits and/or the lambda-limits are stored as a function of engine operating parameters. Thus the control system can always use the optimal parameters for the prevailing conditions, wherein said limits are preferably determined during a calibration procedure. The engine operating parameters on which the limits depend may particularly comprise the mass flow

and the temperature of the exhaust gas entering the TWC.

[0013] The invention further relates to a method for the control of an internal combustion engine with a three-way catalyst (TWC) which comprises the following steps, which are executed in parallel:

a) Controlling the internal combustion engine such that the level of oxygen stored in the TWC lies within predetermined oxygen-storage-limits.

b) Controlling the internal combustion engine such that the lambda value of the exhaust gas within or behind the TWC lies within predetermined lambda-limits.

[0014] To avoid conflicts, step a) is preferably given priority over step b), i.e. step b) is only executed if the conditions of step a) are satisfied.

[0015] The method comprises in general form the steps that can be executed with a control system of the kind described above. Therefore, reference is made to the preceding description for more information on the details, advantages and improvements of that method.

[0016] According to a preferred embodiment of the method, the level of oxygen stored in the TWC is modeled as a function of engine operating parameters, for example of the mass flow, the temperature and/or the lambda value of the exhaust gas entering and/or leaving the TWC.

[0017] The aforementioned modeling may be further improved if it is adapted based on a comparison between a modeled value and the corresponding measured value of an operating parameter, wherein said operating parameter may particularly be the lambda value of the exhaust gas leaving the TWC.

[0018] In the following the invention is described by way of example with reference to the accompanying Figures, in which

Fig. 1 shows a schematic representation of a control system according to the present invention;

Fig. 2 shows the conversion efficiency of a TWC with respect to CO, HC, and NOx as a function of the oxygen storage level in the TWC.

[0019] Future emissions legislation is driving the complexity and cost of automotive vehicles up. The main stay of achieving compliance currently resides with TWC technology in the aftertreatment system, a topic that is addressed with the present invention.

[0020] Figure 1 schematically depicts an internal combustion engine 2 which produces exhaust gas with a lambda value (i.e. normalized air-fuel-ratio) λ_e . The exhaust gas passes through a three-way catalyst TWC 4 in which the emissions of carbon monoxide CO, hydrocarbons HC, and nitrogen oxides NOx are treated. In the

case shown in Figure 1, the TWC 4 consists of two bricks 4a, 4b, and the lambda value λ_c of the exhaust gas within the TWC is measured between these two bricks by means of a HEGO sensor 5. This sensor layout is typical of current systems. A layout with the HEGO placed downstream of the entire catalyst volume would however possibly lead to further optimized control in this instance.

[0021] The control system comprises a first control loop with a lambda-controller 7 that shall guarantee operation of the TWC 4 with optimal efficiency under steady state conditions. The lambda-controller 7 receives as input the difference between a desired HEGO voltage, $HEGO_{ref}$, and the corresponding measured HEGO voltage, $HEGO_{mes}$, sensed by the HEGO sensor 5. The lambda-controller 7 then controls the internal combustion engine 2 such that the difference ($HEGO_{ref} - HEGO_{mes}$) is minimized. This approach is based on the fact that optimum steady state conversion efficiency from a TWC can be directly mapped against post/mid converter HEGO voltage $HEGO_{mes}$ (which is a function of catalyst lambda λ_c). Best conversion of all three pollutants CO, HC, and NOx is normally found between $HEGO_{mes} = 0.5-0.65V$. The converter operates then very close to true stoichiometry. The best conversion lambda can be targeted under these conditions because the converter inlet lambda can usually be guaranteed within tight limits and large lambda excursions need not be considered. However, it is when controlling to post/mid converter HEGO reference only that optimum buffering of input lambda excursions cannot be guaranteed as this signal contains no information as to the amount of oxygen stored on the catalyst. Moreover, the lambda-controller 7 always lags in response since it is purely a feedback system and thus control action lags any observed error.

[0022] The control system of the present invention therefore further comprises a second control loop, wherein a catalyst-model 6 estimates the oxygen storage level $_{est}$ within the TWC 4 based on inputs from the internal combustion engine 2. Said inputs may for example comprise the mass flow m_F and the temperature T of the exhaust gas entering the TWC as well as the lambda value λ_e at the entrance of the TWC that is measured by an UEGO sensor 3. Suitable realizations of the model 6 may be found in literature (e.g. Balenovic, de Bie, Backx: "Development of a Model-Based Controller for a Three-Way Catalytic Converter", SAE paper no. 2002-01-0475, which is incorporated into the present application by reference). The oxygen storage level $_{est}$ estimated by the catalyst-model 6 is compared to a reference storage level $_{ref}$, and the difference ($_{ref} - _{est}$) between these values is fed to an oxygen-storage-controller 1. This oxygen-storage-controller 1 then determines the desired air-fuel-ratio λ_{e_ref} at the inlet of the internal combustion engine 2 in such a way that the oxygen storage level within the TWC lies within predetermined oxygen-storage-limits, i.e. $\in [_{low}, _{high}]$. In order to guarantee a unique input to the internal combustion engine 2, a switch 8 is provided by which either the oxygen-storage-controller 1 or the lamb-

da-controller 7 is connected to the internal combustion engine 2.

[0023] For checking the validity of the model 6, the downstream lambda signal predicted by the model 6 (scaled with the HEGO sensor characteristic) is compared with the reading HEGO_{mes} of the HEGO sensor 5 to estimate the model error Δ at a time instant. This model error Δ is fed into an observer (i.e. Kalman filter with gain K) which updates the predicted oxygen level in order to cope with noise, system biases and model uncertainties.

[0024] The control system described above uses an embedded model 6 to continuously drive the level of oxygen stored in the TWC to its optimal value, therefore guaranteeing maximum robustness to air/fuel excursions. Once close to the set point, additional control based on HEGO sensor signals via the lambda-controller 7 will provide optimum catalyst conversion efficiency. Therefore, the original system performance is retained while the robustness is improved.

[0025] The oxygen storage level should typically approach 50% full (to buffer excursions during transients) and when this criterion is satisfied the inlet lambda should be controlled to that which results in the highest steady state conversion. Thus the oxygen-storage-controller 1 is preferably used in the first instance to maintain the oxygen store between set limits $_{\text{low, high}}$ (to maintain high conversion during lambda excursions), and when within these limits HEGO controller 7 will be used to further raise the conversion efficiency to the best possible under steady state conditions by supplying the best input lambda reference. As the oxygen storage estimate $_{\text{est}}$ is calculated on-line, the oxygen-storage-controller 1 can revert back to controlling the oxygen storage at times when the store violates the set limits. The model prediction of oxygen store is then used as feedback signal, and the error between the estimated and reference oxygen store signal is fed to the controller 1 that drives the system towards the desired oxygen store level.

[0026] During calibration an optimal steady state catalyst lambda is determined and related to the corresponding HEGO voltage. It is selected on the basis of best three-way conversion in the presence of little or no input excursions.

[0027] The actual reference steady state level of stored oxygen and set limits low, high can be determined on the basis of model conversion characteristics. Set limits determine oxygen store levels at which either HC/CO conversion during rich lambda excursions or NOx conversion during lean inlet lambda excursions substantially decrease. Figure 2 shows the dependence of the conversion efficiency (vertical axis) for CO, HC, and NOx in dependence on oxygen storage level. In this example, a level between $_{\text{low}} = 10\%$ and $_{\text{high}} = 40\%$ demonstrates the best robustness at absorbing lean and rich excursions in input lambda. This value is important as during normal operation the input lambda to the catalyst can be subject to large excursions depending on driver demand. Optimal steady state points can be stored as a map (func-

tion of exhaust flow and temperature) in the control system or engine control unit (ECU).

[0028] The operation of the control system is divided into two modes: tracking and regulating mode. The model 6 operates continuously in either of the two modes. As soon as the inferred oxygen level $_{\text{est}}$ within the catalyst ceria leaves the interval $_{\text{low, high}}$ previously determined (as a consequence of various disturbances), the tracking- or oxygen-storage-controller 1 is switched on. This mode uses the estimated oxygen store level $_{\text{est}}$ as the feedback signal. The controller 1 sets the required engine air-fuel ratio $\lambda_{\text{e_ref}}$, which is achieved by a standard air-fuel ratio engine controller placed in the inner control loop, to return within the desired limits. Once the level of stored oxygen returns to the predetermined interval $_{\text{low, high}}$ of the steady state level, the system switches to the regulating mode, which uses the lambda-controller 7 with a direct feedback from the HEGO sensor. In this way the controlled system achieves extra robustness and low susceptibility to small drifts that are typical for such an application.

Claims

1. Control system for an internal combustion engine (2) with a three-way-catalyst TWC (4), comprising a parallel arrangement of:
 - a) an oxygen-storage-controller(1) which is adapted to control the internal combustion engine (2) such that the level of oxygen stored in the TWC (4) lies within predetermined oxygen-storage-limits $_{\text{low, high}}$;
 - b) a lambda-controller (7) that is adapted to control the internal combustion engine (2) such that the lambda-value (λ_{c}) of the exhaust gas within or a behind the TWC (4) lies within predetermined lambda-limits.
2. The control system according to claim 1, **characterized in that** the lambda-controller (7) is only operative if the level of oxygen stored in the TWC (4) lies within the predetermined oxygen-storage-limits $_{\text{low, high}}$.
3. The control system of claim 1 or 2, **characterized in that** it comprises a HEGO sensor (5) for measuring the lambda-value (λ_{c}) of the exhaust gas within or behind the TWC (4).
4. The control system according to one of claims 1 to 3, **characterized in that** it comprises a catalyst-model (6) to predict the level ($_{\text{est}}$) of oxygen stored in the TWC (4).
5. The control system according to claim 4, **characterized in that** the catalyst-model (6) receives as input signal the lambda-value (λ_{e}), the mass flow (m_{F})

and/or the temperature (T) of the exhaust gas entering and/or leaving the TWC (4).

6. The control system of claim 4 or 5, **characterized in that** the catalyst-model (6) comprises an adaptation unit that is able to adjust the model based on a comparison between the modelled and the measured lambda-value (λ_c) within or behind the TWC (4). 5

7. The control system according to one of claims 1 to 6, **characterized in that** it comprises a memory in which the predetermined oxygen-storage-limits ($\lambda_{low, high}$) and/or lambda-limits are stored as a function of engine operating parameters. 10
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8. A method for the control of an internal combustion engine (2) with a three-way-catalyst TWC (4), comprising the following steps executed in parallel, wherein step a) is preferably given priority over step b): 20
 - a) controlling the internal combustion engine (2) such that the level of oxygen stored in the TWC (4) lies within predetermined oxygen-storage-limits ($\lambda_{low, high}$); 25
 - b) controlling the internal combustion engine (2) such that the lambda-value (λ_c) of the exhaust gas within or behind the TWC (4) lies within predetermined lambda-limits. 30

9. The method according to claim 8, **characterized in that** the level of oxygen stored in the TWC (4) is modelled as a function of engine operating parameters. 35

10. The method according to claim 9, **characterized in that** the modelling is adapted based on a comparison between the modelled and the measured value of an operating parameter. 40

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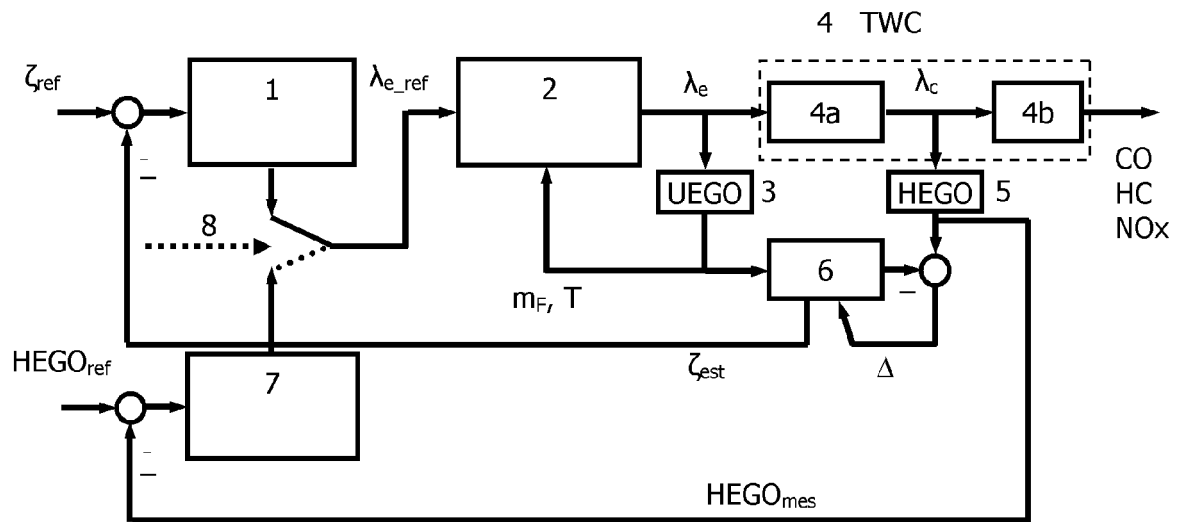


Fig. 1

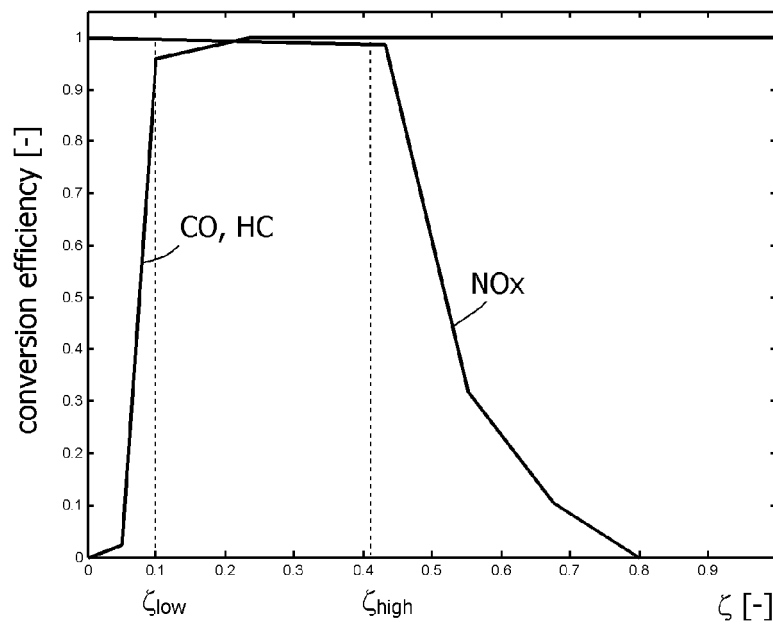


Fig. 2



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EUROPEAN SEARCH REPORT

Application Number
EP 04 10 6631

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 13 May 2005	Examiner Nicolás, C
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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EPO FORM 1503 03.82 (P4/C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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